

BELLCOMM, INC.

SUBJECT: Dependence of AAP-3 Payload on S-IVB
Second Mixture-Ratio Shift Time
Case 610

DATE: October 30, 1967
FROM: I. Hirsch

ABSTRACT

During the powered flight of the S-IVB stage of an Up-rated Saturn I vehicle, the LOX and LH₂ are combined in three successively distinct mixture ratios. The effects on maximum payload (spacecraft) weight caused by varying the duration of the second mixture-ratio burn, T₂, are studied for the AAP-3 mission which has an insertion orbit of 81 x 120 nm.

Choosing T₂ equal to 330 seconds results in the maximum payload. However the allowable payload is relatively insensitive to T₂ near its optimum value. Thus the MSFC requirement that T₂ ≤ 280 seconds can be satisfied with a payload reduction of only 100 pounds.

(NASA-CR-92798) DEPENDENCE OF AAP-3 PAYLOAD
ON S-IVB SECOND MIXTURE-RATIO SHIFT TIME
(Bellcomm, Inc.) 12 p

N79-72313

FF No. 602(A)	(PAGES)	00/18	Unclas
	CR-92798	27	11058
	(NASA CR OR TMX OR AD NUMBER)	(CODE)	
	(CATEGORY)		

~~FOR OFFICIAL USE ONLY~~
~~RESEARCH CENTER ONLY~~

BELLCOMM, INC.

SUBJECT: Dependence of AAP-3 Payload on S-IVB
Second Mixture-Ratio Shift Time
Case 610

DATE: October 30, 1967

FROM: I. Hirsch

MEMORANDUM FOR FILE

1. Introduction

During the powered flight of the S-IVB stage of an Up-rated Saturn I launch vehicle, the LOX and LH₂ are combined in three different mixture ratios, MR_i (i=1, 2, 3), to satisfy essentially two different thrust requirements, viz. a high thrust (MR₂ = 5.5) during the first phase of the powered flight where gravity losses are significant, followed by a shift to a lower mixture ratio (MR₃ = 4.7) to provide a high I_{sp} for attaining orbital insertion velocity. The first mixture-ratio (MR₁ = 5.0) burn lasts for only 1.3 seconds (T₁), during which time the J-2 engine of the S-IVB is stabilized. Using the program recently developed by V. J. Esposito (Reference 1) which simulates Up-rated Saturn I trajectories for earth orbital missions, the effects on inserted spacecraft weight (payload) produced by varying the duration of the second mixture-ratio time, T₂, have been investigated for the AAP-3 mission.

2. The Relationship Between Spacecraft Weight and Second Mixture-Ratio Time

The propellant loading for the S-IVB is discussed in detail in the Appendix. Figure 1 shows a plot of consumable second-stage LH₂ (excludes F.P.R., thrust buildup, thrust decay, and residual propellant) as a function of T₂.

Having determined the propellant requirements for various values of T₂, the simulator program was then "flown" to determine the spacecraft weight associated with each value of T₂ for insertion into an 81 x 120 nm orbit.¹ The results are shown in Figure 2 for a flight azimuth of 82.82° from Launch Complex 34.

¹A typical weight breakdown used in a run of the simulator for T₂ = 300 seconds, is given in Table I. The vehicle performance data for the AAP-3 Mission can be found in Appendix B of Reference 5.

The spacecraft weight exhibits a parabolic dependency on the second MR time, T_2 , and in fact, an empirical spacecraft weight, P , given by

$$P = -.030864T_2^2 + 20.555T_2 + 36772$$

$$182.5 \leq T_2 \leq 411.9$$

differs from the spacecraft weight (as "flown" by the simulator) by no more than 10 pounds over the entire range of T_2 values under consideration. The lower bound of 182.5 seconds for T_2 is set by the capacity of the LH_2 tanks, while the upper bound of 411.9 seconds is fixed by the capacity of the LOX tanks. Figures 1 and 2 exhibit an apparently paradoxical effect, in that loading the LH_2 tanks to capacity results in a less-than-optimal spacecraft weight of 39,500 pounds, or in other words, removing LH_2 from the S-IVB will yield a greater payload.

It should be noted that although the maximum allowable spacecraft weight corresponds to $T_2 = 330$ seconds, the payload is not very sensitive to T_2 in the vicinity of this maximum. In fact, for values of T_2 between 276 and 388 seconds, the allowable payload differs from the maximum by only 100 pounds or less.

As shown in Figure 2, the third mixture-ratio time, T_3 , is 100 seconds for the optimum payload situation. That is, the MR shift from 5.5 to 4.7 would occur relatively close to S-IVB shutdown. MSFC has adopted a general rule that the MR shift should occur not later than $T_2 = 280$ sec in order to allow sufficient time for guidance corrections necessitated by thrust fluctuations resulting from the MR shift. Maintaining this constraint would then result in a payload reduction of about 100 pounds.

3. Conclusions

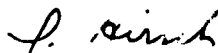
The payload inserted into 81 x 120 am on the AAP-3 Mission can be maximized by choosing the duration of the second mixture-ratio burn, T_2 , equal to 330 seconds. Because of the relative insensitivity of allowable payload to T_2 near its optimum

value, the MSFC ground rule requiring $T_2 \leq 280$ seconds can be maintained with a payload reduction of only 100 pounds.

Although based on simulations using data for Uprated Saturn I 209, currently assigned to AAP-3, these results are generally applicable to Uprated Saturn I flights to similar low-altitude orbits, in particular to AAP-1 which also has an initial orbit of 81 x 120 nm. However, additional simulations must be run to determine the optimum value of T_2 for the payloads of flights along other trajectories such as AAP-2 and AAP-4.

4. Acknowledgments

The assistance rendered by Miss L. K. Hawkins in writing the computational programs for this memorandum is gratefully acknowledged, as is the help of V. J. Esposito and P. H. Whipple in the use of the BCMASP program.



I. Hirsch

1021-IH-dcs

Attachments

Figure 1

Figure 2

Table 1

Appendix

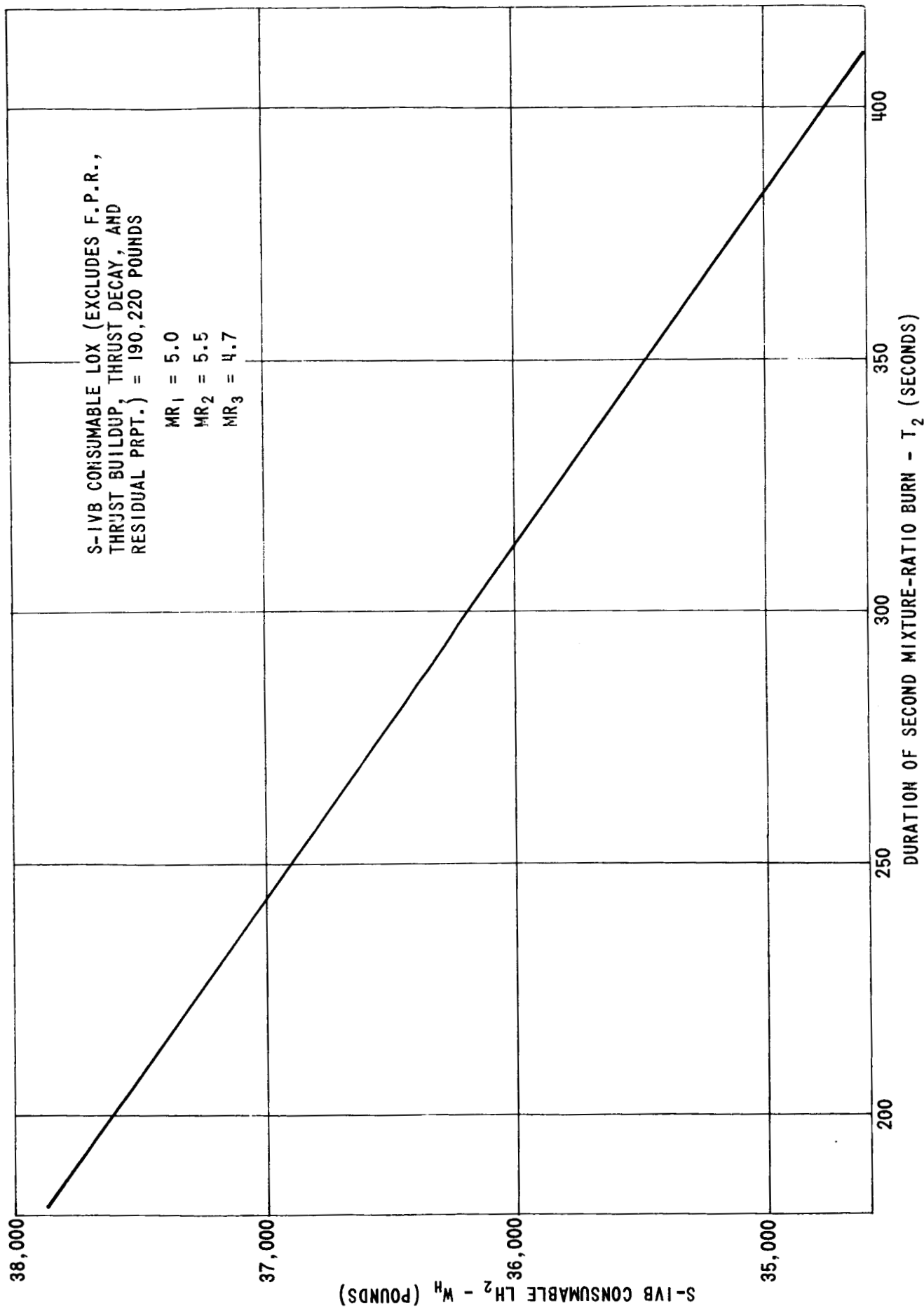


FIGURE 1 - CONSUMABLE LH₂ (EXCLUDES F.P.R., THRUST BUILDUP, THRUST DECAY, AND RESIDUAL PRPT.) AS A FUNCTION OF THE SECOND MR TIME

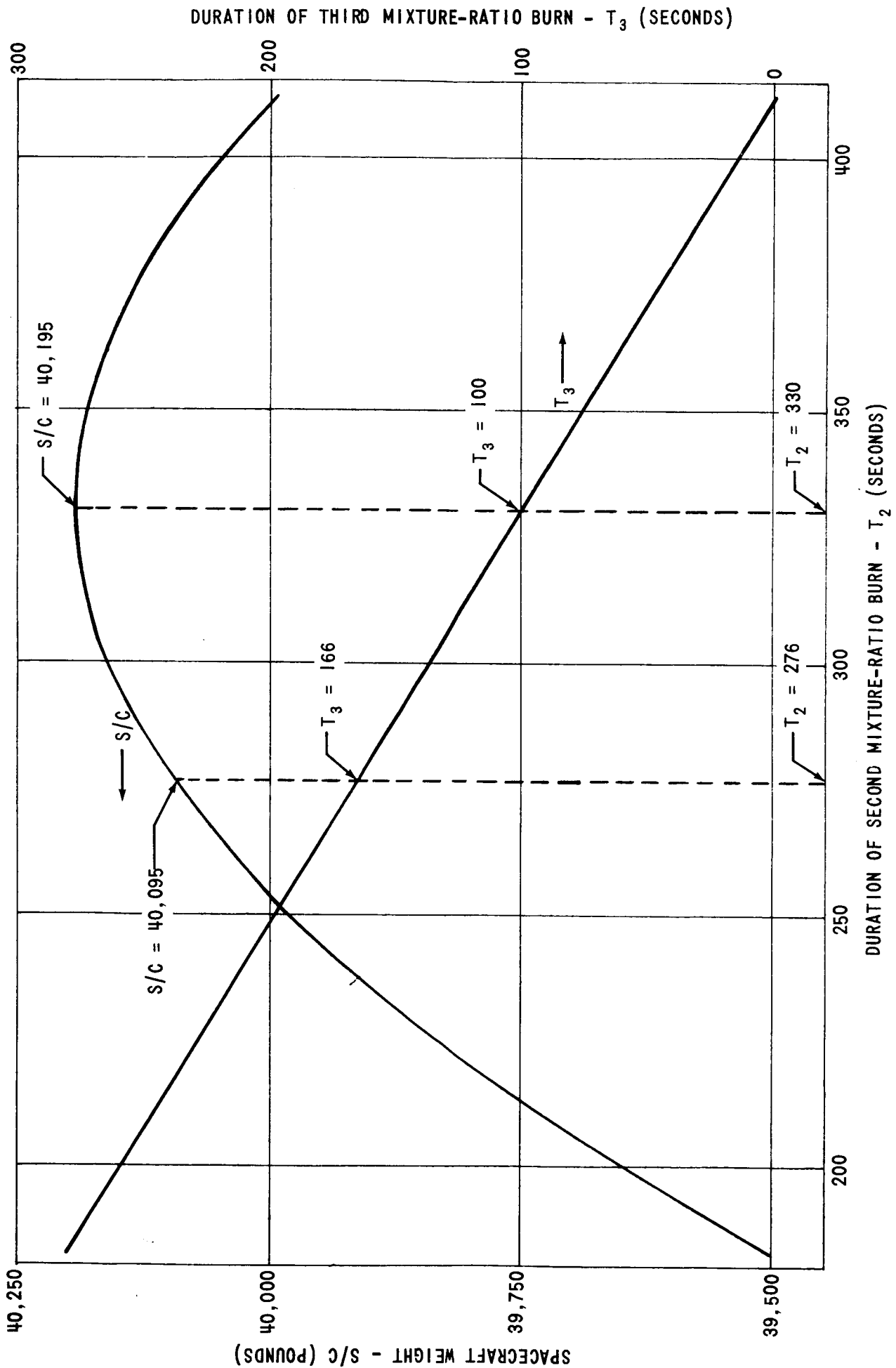


FIGURE 2 - DEPENDENCE OF SPACECRAFT WEIGHT AND THIRD MR TIME ON SECOND MR TIME

TABLE I - VEHICLE WEIGHTS FOR AAP-3 MISSION⁴ (POUNDS)

70,298	INSERTION WEIGHT:
	40,159 - SPACECRAFT
	4,143 - INSTRUMENT UNIT
	22,015 - S-IVB STAGE, DRY
	1,500 - S-IVB FLIGHT PERFORMANCE RESERVE PROPELLANT (1,250 LOX, 250 LH ₂)
	2,481 - S-IVB RESIDUAL PROPELLANT
235,079	S-IVB CONSUMED AND JETTISONED WEIGHT:
	190,220 - S-IVB LOX CONSUMED
	36,189 - S-IVB LH ₂ CONSUMED (T ₂ = 300 SECONDS)
	8,450 - LAUNCH ESCAPE SYSTEM
	220 - S-IVB ULLAGE ROCKET CASES
101,422	S-IB JETTISONED WEIGHT:
	6,514 - S-IVB/S-IB INTERSTAGE
	83,761 - S-IB STAGE, DRY
	10,492 - S-IVB FLIGHT PERFORMANCE RESERVE AND RESIDUAL PROPELLANT
	655 - OTHER ITEMS
888,218	S-IB EXPENDED WEIGHT AT SEPARATION:
	882,220 - S-IB PROPELLANT CONSUMED
	4,162 - S-IB THRUST DECAY PROPELLANT
	1,000 - S-IVB FROST
	836 - OTHER ITEMS (INCLUDES 100 LBS S-IVB FROST)
1,295,017	LIFT-OFF WEIGHT

⁴BASED ON DATA IN REFERENCES 2-4.

BELLCOMM, INC.

APPENDIX

Propellant Loading for S-IVB

The rate (in lbs/sec) at which LH_2 is consumed,² \dot{W}_{H_i} , is computed from the basic definition of mixture ratio:

$$\dot{W}_{H_i} = \left(\frac{1}{1+MR_i} \right) \dot{W}_{P_i} , \quad (1)$$

where \dot{W}_{P_i} is the (constant) rate at which propellant is consumed during the i -th mixture ratio. Consequently, the (constant) LOX consumption rate, \dot{W}_{O_i} , is given by,

$$\dot{W}_{O_i} = \dot{W}_{P_i} - \dot{W}_{H_i} . \quad (2)$$

The weights of consumable LOX and LH_2 required for the i -th MR setting may then be computed from,

$$W_{H_i} = \dot{W}_{H_i} \cdot T_i , \quad (3)$$

$$W_{O_i} = \dot{W}_{O_i} \cdot T_i , \quad (4)$$

T_i being the duration of the i -th mixture-ratio burn.

²In the ensuing discussion, the subscript i will always denote the value of the quantity being considered for the i -th mixture ratio, MR_i .

If W_O and W_H denote the weights of total useable³ S-IVB LOX and LH_2 respectively, then,

$$W_H = \sum_{i=1}^3 W_{H_i} = \sum_{i=1}^3 \dot{W}_{H_i} \cdot T_i \quad , \quad (5)$$

$$W_O = \sum_{i=1}^3 W_{O_i} = \sum_{i=1}^3 \dot{W}_{O_i} \cdot T_i \quad , \quad (6)$$

where $W_O = 190,220$ pounds (from Reference 2) for the S-IVB LOX tanks filled to capacity. The amounts of LH_2 and LOX consumed during the second and third mixture-ratio burns are given by,

$$W_{H_2} + W_{H_3} = \dot{W}_{H_2} \cdot T_2 + \dot{W}_{H_3} \cdot T_3 \quad , \quad (7)$$

$$W_{O_2} + W_{O_3} = \dot{W}_{O_2} \cdot T_2 + \dot{W}_{O_3} \cdot T_3 \quad . \quad (8)$$

Since \dot{W}_{H_2} , \dot{W}_{H_3} , \dot{W}_{O_1} , \dot{W}_{O_2} , and \dot{W}_{O_3} are known from equations (1) and (2), and $W_{O_2} + W_{O_3}$ can be computed for $T_1 = 1.3$ seconds from

³"useable" excludes flight performance reserve, thrust buildup, thrust decay, and residual propellant.

$$W_{O_2} + W_{O_3} = W_0 - W_{O_1}$$

$$= W_0 - \dot{W}_{O_1} \cdot T_1$$

$$= 190220 - \dot{W}_{O_1} \cdot (1.3) \quad , \quad (9)$$

(7) and (8) provide two equations in two unknowns, $W_{H_2} + W_{H_3}$ and T_3 , for arbitrarily assigned values of T_2 . W_0 is always assumed to be equal to 190,220. Hence, the LH_2 required for the powered flight of the S-IVB is determined from

$$W_H = W_{H_1} + (W_{H_2} + W_{H_3})$$

$$= \dot{W}_{H_1} \cdot T_1 + (W_{H_2} + W_{H_3}) \quad . \quad (10)$$

A plot of W_H versus T_2 is found in Figure 1.

BELLCOMM, INC.

REFERENCES

1. "A Computer Program for Simulating Up-rated Saturn I Trajectories", by V. J. Esposito, Bellcomm Technical Memorandum, TM-67-1021-2, September 21, 1967.
2. "AAP-2 (AS-209) Preliminary Reference Mass Characteristics", MSFC Memorandum, R-P&VE-VAW-67-86, June 9, 1967.
3. "Weight Status Reports for the Saturn I-B Launch Vehicles", MSFC Memorandum, R-P&VE-VAW-67-106, August 2, 1967.
4. "Launch Vehicle Preliminary Reference Trajectory; AAP-1 Mission", Chrysler Technical Note, TN-AP-67-186, March 14, 1967.
5. "Payload Capabilities for Apollo Applications Missions", by V. J. Esposito and I. Hirsch, Bellcomm Memorandum for File, October 16, 1967.

BELLCOMM, INC.

Subject: Dependence of AAP-3 Payload on S-IVB
Second Mixture-Ratio Shift Time
Case 610

From: I. Hirsch

Distribution List

NASA Headquarters

Messrs. H. Cohen/MLR
P. E. Culbertson/MLA
J. H. Disher/MLD
J. A. Edwards/MLO
L. K. Fero/MLV
J. P. Field/MLP
T. A. Keegan/MA-2
C. W. Mathews/ML
M. Savage/MLT

Bellcomm, Inc.

Messrs. A. P. Boysen
D. R. Hagner
W. C. Hittinger
B. T. Howard
J. Z. Menard
I. D. Nehama
I. M. Ross
R. L. Wagner
Division 101 Supervision
Division 102 Supervision
All Members Depts. 1021, 1022 & 1024
Department 1023
Central File
Library